CALIFORNIA DIVISION OF MINES AND GEOLOGY
FAULT EVALUATION REPORT FER-231

The Concord fault, Contra Costa County, California

by

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INTRODUCTION

The Concord fault was first mapped by Poland (1935) and recognized by Sharp (1973) as an active, creeping fault. It was included within Alquist-Priolo Special Studies Zones in 1974. Since that time, the Concord fault has been studied in more than 130 site-specific investigations. As a result, it is clear that some traces on the existing Special Studies Zones maps are accurately located, but others are not well located or could not be verified. This report reviews the accumulated published and unpublished reports to determine if all of the strands of the Concord fault shown on the existing Special Studies Zones maps meet the criteria of "sufficiently active and well defined" (Hart, 1990) for zoning under the Alquist-Priolo Act.

REVIEW OF PREVIOUS WORK

REGIONAL STUDIES

The Concord fault is a N 30°W-trending right-lateral fault, part of the San Andreas fault system in the California coast ranges. It extends for about 18 km along the edge of Ygnacio Valley from the base of Mount Diablo to Suisun Bay (Figure 1).

The Concord fault was originally discovered as a result of a lawsuit by ranchers in the Ygnacio Valley who alleged that pumping of groundwater by the Port Costa Water Company was adversely affecting their wells. The resulting investigations generated a large volume of data on the groundwater of the Ygnacio Valley, particularly the Concord area. Poland (1935) reviewed the court documents and recognized that the prominent, linear, groundwater barrier through Concord was a fault in the alluvium. He named this fault the Concord fault and showed it on his geologic map of the area.

After Poland mapped the fault, it was shown on the 1938 geologic map of California (Jenkins, 1938) but was generally not shown on later maps of the region (Bowen and Crippen, 1951; Colburn, 1961; Jennings and Burnett, 1961). It was shown by the California Department of Water Resources (1964). The fault was "rediscovered" by Sharp (1973) who produced a strip map and described evidence for right-lateral fault creep. Sharp divided the fault into three segments based on differences in geomorphic expression and the amount of observed creep. These three segments were named, from north to south, the Avon, Concord, and Ygnacio segments, For simplicity these are referred to here as the northern, central, and southern segments, although Sharp's segment boundaries are retained. Further discussion of the fault will be divided among these segments.

The northernmost part of the fault mapped by Sharp (1973) was initially defined by a possible creep locality on the north side of Suisun Bay in Solano County. From there it is projected across Suisun Bay, through the marshes at the mouth of Pacheco Creek and to the southeast along the west-facing escarpment of "Tank Farm Hill" and smaller escarpments in the Avon and Buchanan Field areas. Much of the trace of the fault through this area is shown by Sharp (1973) to be coincident with the linear channel of Walnut Creek. Sharp noted that two bridges that cross the fault were right-laterally deflected, suggesting that the main strand was creeping (Figure 2).

The mapped fault on the north side of Suisun Bay was evaluated by Hart (1976) based on review of consultants reports (Harding Lawson Associates, 1974; 1976) and field observations. No fault could be verified on aerial photos or in excavations. Consequently, this part of the Special Studies Zone was withdrawn in 1977. Rather than extending across Suisun Bay, the Concord fault currently is thought to end in the bay. The right-lateral slip may be transferred through a right-step to the right-lateral Green Valley fault north of the bay (Figuers, 1991; Bryant,1991). The part of the fault mapped north of Suisun Bay will not be discussed further in this report.

Sharp mapped a short eastern strand of the fault in the Avon area which is defined by right-laterally offset, man-made features on a low, elongate hill (Figure 2). Sims and others (1973) mapped another eastern trace extending southeast from Avon (Figure 2). Both of these traces are in areas underlain by Quaternary alluvium or bay mud (Sims and others, 1973; Dibblee, 1981). No creep has been noted along the eastern trace of Sims and others (1973).

The central segment is characterized by a series of linear scarps and associated tonal features, much of which coincides with fault creep (Sharp, 1973)(Figure 2). (Dibblee, 1980a) shows this fault to be developed in Quaternary alluvium. This segment was also mapped by Poland (1935) based on a groundwater barrier. Sharp shows the central segment as a series of short (up to 1 km long), discontinuous fault strands, some in a right-stepping en echelon pattern and some parallel to others (Figure 2). Poland, in contrast, shows a single straight trace through this area.

Most of the localities where Sharp was able to document creep are within the central segment. He described right-lateral offsets of curbs of up to 15 cm. Galehouse (1990) has monitored creep at two stations across the central segment since 1979 (Figure 2). He documents right-lateral fault creep at an average rate of about 3 mm/yr. This slip occurs episodically with 7 to 10 mm of slip accumulating in a few months, followed by 3 - 4 years of very slight creep.

The southern segment was projected to the southeast from the central segment along the base of the prominent west-facing escarpment of Lime Ridge (Poland, 1935; Sharp, 1973) (Figure 2). Sharp was unable to find any "direct evidence" for the location of the fault in this area. Dibblee (1980a,b) shows Quaternary alluvium in Ygnacio Valley concealing the trace of the fault.

Geologic relationships at the southern end of the Concord fault are complex. Dibblee (1980b,c) shows the southeasternmost strand of the Concord fault to connect with the Mount Diablo fault and other strands to splay to the south. The Mount Diablo fault, a north-dipping thrust fault is mapped as connecting strands of the right-lateral Greenville fault and the Concord fault through a complex left step (ESA, 1982).

Some of the splays mapped by Dibblee (1980a,b,c) trend slightly west of south toward the Calaveras fault. These faults extend into the area of the 1990 Alamo earthquake swarm. The 1990 Alamo swarm and the 1970 Danville swarm (see further discussion under seismicity) suggest a complex transfer of right-lateral slip from the Calaveras fault to the Concord fault (Figure 4).

SITE SPECIFIC STUDIES

Since Alquist-Priolo Special Studies were first established in 1974, over 130 consulting geologists' studies have been conducted on the Concord fault and filed with the Division of Mines and Geology. These reports have been reviewed for this study and are briefly summarized in Table 1 which refers to them by AP or C-file numbers. Locations of trenches and other pertinent data are shown on Figure 2. The general conclusions of these studies are discussed below, from north to south.

Northern segment

Main trace

As discussed above, much of the northern segment is concealed beneath Suisun Bay and the marshes at the mouth of Pacheco Creek. The location of the main trace of Sharp (1973) is largely based on deformation of the Santa Fe Railroad and Waterfront Road bridges. Few consulting geologists have studied this segment.

Rogers/Pacific (1988, C-780) field-checked evidence for creep, conducted a gravity survey, and interpreted boring logs for a site northwest of "Tank Farm Hill". Both bridges were found to be deformed in a manner consistent with right-lateral creep, but Rogers/Pacific concluded that poor foundation conditions and dredging of the creek channel may have caused deformation of the Santa Fe Railroad Bridge, and possibly also the Waterfront Road Bridge.

The gravity survey showed anomalies at three locations north of Highway 4 that are similar to one at Willow Pass Road, where the fault is well defined by creep and other evidence (Figure 2). These anomalies, which are generally about 800 feet wide, are located beneath the channel of Walnut and Pacheco Creeks west of "Tank Farm Hill". They are interpreted to be consistent with a "near vertical contact between geologic units with contrasting densities" (Rogers Pacific, 1988) suggesting a fault.

Deep borings interpreted by Rogers/Pacific (1988) show Panoche Formation bedrock, which crops out on "Tank Farm Hill", more than 200 feet below sea level west of Walnut Creek. In two borings on the west bank of the creek, B-116 and B-117, the Panoche Formation bedrock is sheared and slickensided (Locality 1, Figure 2). A third boring to the north, B-115, encountered Miocene bedrock (which has not been mapped in the surrounding area) at 329 feet and remained in Miocene rocks to its total depth of 500 feet. Rogers/Pacific concluded that the trace of the Concord fault probably parallels the bank of Walnut Creek close to borings B-117 and B-116. A fault also probably separates B-115 from B-116. Faults shown on Figure 2 are interpreted for this report from the data presented by Rogers/Pacific. Faults at these locations are consistent with the gravity anomalies at the Santa Fe Railroad and Waterfront Road, but may be up to about 500 feet east of the main trace mapped by Sharp (1973). The Miocene bedrock encountered in B-115 may represent a sliver of bedrock in the fault zone that has been transported from some unknown distance.

South of the area studied by Rogers/Pacific, Caltrans (1979, filed with AP-1712) conducted a engineering geology investigation for the construction of new bridges across Walnut Creek at Imhoff Drive and Highway 4 (Locality 2, Figure 2). This investigation included 10 rotary borings and 4 cone penetrometer tests at the Imhoff Drive bridge and 11 borings and 7 cone penetrometer tests at the Highway 4 bridges (Figure 2). Rotary borings included Standard Penetration Tests approximately every 5 feet. Samples recovered in the penetrometer were described and graphic logs drawn.

At the Imhoff Drive bridge (Locality 2a, Figure 2), logs of 10 rotary borings in a line perpendicular to the fault show gray clay and silty clay at the surface (probably "bay mud") usually underlain by a thin layer of sand and gravel above siltstone or claystone bedrock. The contact between the bedrock and the overlying sand and gravel is at about 35 to 45 feet below sea level in the 6 borings from B-11, west. In boring B-12 the bedrock-alluvium contact is at -29 feet and the sand and gravel is absent. In the 3 borings from B-13 east, the contact between bedrock and the thin overlying sand and gravel is at -8 to -10 feet. The nearly horizontal bedrock-alluvium contact and overlying sand and gravel layer at different elevations west from boring B-11 and east from B-13 strongly suggests a fault offseting the sand and gravel layer and the base of the "bay mud". The intermediate elevation of the bedrock- alluvium contact at boring B-12 and the lack of the sand and gravel layer there suggest that the fault may be close to that boring.

At Highway 4 (Locality 2b, Figure 2), logs of the three western borings show a similar bedrock-alluvium contact between -25 and -35 feet. In the next boring to the east (B-12, not the same boring as Imhoff Drive B-12), Caltrans describes "gray, fracture sandstone in dark gray matrix of clay gouge, gray very fine grain sandstone with shale seams (vertical bedding)". In the next three borings to the east the bedrock-alluvium contact is between -55 and -72 feet, suggesting 20 to 30 feet of down-to-the-east displacement. East of boring B-12 the bedrock is overlain by a 40 foot thick sequence of sand, silty sand and sand and gravel with minor clay, very different from anything to the west. The boring data suggest another fault at the east end of the bridge, where the bedrock-alluvium contact rises from -72 feet in B-13 to -23 feet in B-19, suggesting down-to-the-west displacement. To the east the bedrock-alluvium contact varies between -15 and -50 feet, suggesting additional strands of the fault in this area.

Differing bedrock types east and west of B-12 also suggest that a fault may pass close to that boring. Borings west of B-12 encountered "gray shale" with minor siltstone and claystone. Borings east of B-12 encountered sandstone and siltstone with minor claystone and shale.

Geologic consultants have also investigated three properties near the old State Highway 4 bridge over Walnut Creek. The consultants all ran resistivity or seismic refraction lines to attempt to locate faults (Kaldveer and Associates, 1984, AP-1712; Engeo Inc, 1977, AP-1741; Woodward-Clyde Consultants, 1985, AP-1809). None of these studies found evidence for faulting on the individual parcels but none included trenches to verify the subsurface materials. Engeo also measured the water level in 4 borings on both sides of the channel. In two borings west of the channel the water table was 8 to 10 feet lower than in two borings east of the channel. Engeo proposed that the difference in elevation was a result of a groundwater barrier along the Concord fault.

Eastern traces

Rogers/Pacific (1988, C-780) also examined the short trace mapped by Sharp (1973) based on evidence for creep. Rogers/Pacific was able to verify some aligned, right-laterally offset features and concluded that tectonic creep was the most likely explanation for them. Todd Nelson, then Contra Costa County Geologist, also checked parts of this trace for evidence of creep (T. Nelson, written communication to E. Hart, 1981). Nelson examined the area where Sharp noted "small RL offset of concrete walls" (Locality 3, Figure 2) but was unable to verify any right-lateral offset of the walls, or any deformation consistent with right-lateral movement in them or in the surrounding buildings.

Nelson (p.c. to Hart, 1981) also checked buildings and an oil storage reservoir on the eastern trace mapped by Sims and others (1973) and was unable to find any evidence for creep. Several consultants have investigated properties near this trace. Trenches cluster around the southern end of the mapped fault, but only one (Kaldveer and Associates, 1983, AP-1562) crossed it. This trench showed continuous, horizontally bedded clay alluvium and overlying soil for 600 feet across the center of the Special Studies zone. Trenches by others (Figure 2) cross the rest of the zone to the south. No faults were found in any of the trenches.

Central segment

The central segment of the Concord fault has been extensively studied because it passes just west of the center of downtown Concord, through an area that has been largely developed or re-developed since the passage of the Alquist-Priolo Act. Among the consultants' studies is a report by Earth Science Associates (1977, C-781) for the City of Concord. ESA reviewed aerial photographs and previous consultants reports and conducted field reconnaissance to determine the activity and location of the fault in central Concord. Their maps show a main trace (A) similar to the main trace of Sharp (1973), three secondary traces (B,C, and D) southwest of the main trace, and two possible secondary traces (E) northeast of the main trace (Figure 2). Subsequent consultants reports have examined the main trace, secondary traces mapped by Sharp, and secondary traces mapped by ESA.

Consultants' studies in central Concord have reported trench exposures of the Concord fault along a relatively straight, narrow zone from the point where it diverges from the channel of Walnut Creek southeastward to Keller Lake (Figure 2). Trench exposures commonly show several fault strands in a zone up to about 40 feet wide. Faults located by trenching are up to 200 feet east of the trace mapped by Sharp (1973) and up to 100 feet west of the eastern trace (from Burkland and Associates, 1975) shown on the Special Studies Zones map (CDMG, 1974a). Trench exposures of faults fall on a straight line with a trace of a left-stepping pattern in the area mapped by Sharp and ESA (1977) as a left step in the main trace (south of Concord Ave, Figure 2).

The secondary faults proposed by Sharp and ESA southeast of the main trace have been trenched in many locations. One trench, by Zickefoose and Associates (1975, AP-456) found that a "sandy conglomerate" was truncated against a "sandy clay" at the southwest end of a trench (Locality 4, Figure 2). Zickefoose interpreted this truncation to be a fault. ESA interpreted the fault found by Zickefoose as confirming their "lineament B" (Figure 2). Other trenches across "lineament B" (Consulting Quality Control Engineers, 1975, AP-2609; Engeo, 1980, AP-1390; A. Kropp and Associates, 1983, AP-1545) have failed to verify a fault, however. Trenches across other proposed secondary faults southwest of the main trace have also failed to verify faults in the subsurface. The proposed secondary faults northeast of the main trace have not been investigated by trenching, nor has the proposed trace mapped along the southwest side of Keller Lake by Sharp (1973) and projected to the north by ESA.

Sharp (1973) shows the Concord fault bounding the east side of Keller Lake and then continuing to the south. Engeo (1978,1984, AP-1699) logged three trenches across Sharp's main trace south of Keller Lake but were unable to verify the fault. They concluded that the fault was west of the site of their investigation near the base of the slope. To the south, consultants' trenches are not as closely spaced because the area was largely developed before the Alquist-Priolo Act was passed. Engeo (1984, AP-1660) did, however, observe the fault in an excavation by the Army Corps of Engineers in the Galindo Creek channel (Locality 5, Figure 2).

Several trenches have been excavated across the trace of the fault at the southern end of the central segment. None of these trenches, by Soares and Associates (1977, AP-1191); Western Geological Consultants (1979, AP- 1388) and Engeo (1989, AP-2358), found any indication of faulting in horizontally bedded alluvium. A study by J.V. Lowney and Associates (1977, C-300), west of the mapped trace of the fault, noted different groundwater levels between the "east end of the property", where the groundwater was 1 foot below the surface, and "the middle of the site", where groundwater was at 14 feet below the nearly level ground surface (Locality 6, Figure 2). J.V. Lowney and Associates later installed a drainage system and trenched the site. They found no indications of faulting in horizontally bedded alluvium or indications of a groundwater anomaly after the site had been drained.

Southern segment

At the north end of the southern segment, Purcell Rhoades and Associates (1975, AP-631) noted that "lithologic variations between banks of Pine Creek" suggests that the fault follows the creek channel. Their trench logs show an increase in the thickness of a silty clay layer, pinching out of other layers and an increase in slickensides in the clay layer toward the creek. Although they were unable to trench across the creek, they concluded that the Concord fault was obscured by the creek.

Purcell, Rhoades and Associates (1978, AP-781) logged two other trenches across the mapped trace of the fault south of Treat Road (Figure 2). The trenches were up to 13 feet deep in horizontally bedded alluvium with weak soil development. No faults were found in this material, which may be of very recent origin. Purcell, Rhoades did note that the water level was 24 feet below the surface in one boring near Pine Creek, and 9 feet below the surface at another boring about 300 feet farther from the creek, 1400 feet to the south. Purcell, Rhoades did not consider the difference in groundwater elevations to be related to faulting.

The area around the south end of the Concord fault, near North Gate Road in Walnut Creek, has been developed into residential tracts since passage of the Alquist-Priolo Act. As a result, numerous trenches have been excavated to locate the fault. Several consultants (Terrasearch, 1987, AP-2327) (Bay Soils, 1980, D. Myers, 1985, Engeo, 1989, all AP-1840) (Engeo, 1990, AP-2434) (Berlogar, 1981; Harding Lawson, 1984; Geosoils, 1986, Engeo, 1987, all AP-2074) located faults in trenches and established building setback zones near Sharp's inferred trace. However, these faults to not align well from trench to trench. Setbacks have been based on faults in bedrock and alluvium, local thickening of the overlying colluvium, and geophysical anomalies.

These trenching studies have found evidence for faulting of late Quaternary age but none have found clear evidence of Holocene faulting or a through-going recent fault. Terrasearch (1987, AP-2327) logged a 35-foot wide zone of northwest-trending, southwest-dipping faults which offset the contact between "claystone bedrock" and "pebbly to gravelly clay" down to the southwest (Locality 7a, Figure 2). None of these faults offset the overlying soil or colluvium. Other trenches to the southeast (Berlogar,1981; Geosoils,1986, AP-2074) exposed a fault zone at the base of the slope, close to Sharp's trace. Both describe a zone of intense shearing in bedrock that is several feet thick. Berlogar noted a thickened zone of "claystone in matrix of sheared claystone" (possibly representing faulted colluvium but also possibly weathered sheared bedrock) west of the fault. Geosoils (Locality 7b, Figure 2) noted Panoche Formation bedrock is relatively uplifted to the west with the fault at least partially overlain by Quaternary "terrace" deposits. They show a

6" thick gouge zone and zone of "highly sheared" bedrock along the fault in bedrock. Neither consultant described disruption or offset of overlying soil horizons, although these soils are thin clayey soils that are likely to be affected by creep.

The age of the soils that overlie the fault is not known and few consultants note features such as color, soil structure or clay films that could indicate the age of the soils. Engeo (1989, AP-1840) does note that the soil overlying the fault in one trench (Locality 7c, Figure 2) is "well developed" and has a "reddish-brown hue," suggesting a pre-Holocene age. Engeo radiocarbon dated "scattered small specs of carbon" from the alluvium west of the fault and found it to be greater than 28,500 years old. However, the relationship between the age of this alluvium and the alluvium and soils which overlie the fault is unclear. The dated alluvium is described as a yellowish brown to red brown sandy clayey silt with minor gravel, which is somewhat similar to the description of Quaternary terrace deposits described by Geosoils (1986, AP-2074). This soil is also similar to the Positas loam described by Welch (1977) as a well-developed soil formed on older terrace remnants.

The description of the dated alluvium is also similar to alluvium west of the fault described by Burkland and Associates (1973, AP-2083) and Terrasearch (1987, AP-2373). Neither Burkland nor Terrasearch determined the relationship between this alluvium and the Concord fault. Burkland did, however, find a short secondary fault cutting alluvium. This fault was included within an Alquist-Priolo Special Studies Zone (CDMG 1974b) based on a personal communication from the project geologist, M. Levish (1973). Trenching along the trend of this fault to the north (Terrasearch, 1978, AP-2082; A. Soares and Associates, 1980, AP-2307; Harding Lawson Associates, 1990, AP-2373) did not find further evidence of faulting, although Harding Lawson proposed that the fault could extend west of the trenches along a southwest-facing "break-in-slope" (scarp).

In the hills to the east, Harding Lawson (1984), Geosoils (1986), and Engeo (1987) (all AP-2074) found that faults and shears, commonly along bedding planes, were pervasive throughout the Panoche formation and locally were associated with thickened colluvium, although none have the gouge zone noted by Geosoils (1986) at the base of the hills. These faults and shears have a wide variety of orientations, are not clearly active themselves, and could not be definitely related to any active faults.

Geomorphic features shown on Figure 3 and discussed in the next section have been crossed by several trenches. A tonal east of North Gate Road, and west of Sharp's trace of the fault was trenched by Engeo (1989, AP-1840) (Locality 8, Figure 2). Their trench N-3 exposed thick dark grayish brown and olive brown clay alluvium, possibly representing a filled depression, at this tonal lineament. Trench N-4, immediately to the west, exposed intensely faulted bedrock and irregularities in the bedrock-alluvium contact.

A trough and tonal lineament roughly coincident with North Gate Road is considered by Hart (unpublished) to be the strongest evidence for recent faulting along the southern Concord fault. Western Geological Consultants (1990, AP-2393) report no features which they interpreted to be due to faulting on a parcel west of North Gate Road. WGC reports bedrock within three feet of the ground surface on the west side of North Gate Road in their trench 1. Near the east end of their trench 2, adjacent to North Gate Road, WGC shows an east-dipping zone of "red-brown clay" which separates bedrock and alluvium to the west from alluvium to the east. The contacts of this zone were gradational and not sheared (T. Nelson p.c. 1992) suggesting that they are depositional or soils contacts, rather than faults. Immediately across the road to the east Engeo (1989, AP-1840)(trench N-6) reports young alluvium over ten feet thick that is apparently thickening toward the road. This contrast in materials suggests a discontinuity beneath North Gate Road.

To the south, Engeo (1990, AP-2434) found a fault in Quaternary alluvium just beyond the end of the fault mapped by Sharp (1973), and virtually coincident with a tonal lineament mapped by Hart (Locality 9, Figure 2). Engeo radiocarbon dated a "sample of organic material" from unfaulted silty clay overlying the faulted alluvium. This sample was found to be 7,580±710 years old. The "organic material" was minute flecks of carbon, probably of detrital origin (D. Carey p.c. 1992), the deposit that contained it could be somewhat younger.

INTERPRETATION OF AERIAL PHOTOGRAPHS AND FIELD CHECKING

Geomorphic evidence for faulting along the trace of the Concord fault was interpreted on aerial photographs and checked in the field. Previous photo interpretations by E.W. Hart (1979-1988, unpublished) were also consulted. Photo interpretations and field observations are plotted on Figure 3. Aerial photographs of about 1:20,000 scale, taken by the USDA in 1939 and 1950 were used extensively. Photographs of 1:20,000 scale taken by the USGS in 1973, and photographs of approximately 1:24,000 scale taken by WAC Corporation in 1984 also were used. Aerial photographs of 1:12,000 scale taken by Cartwright Aerial Surveys (1973) were also consulted at the Contra Costa County Community Development Department. Field checking of geomorphic features was done in conjunction with field checking of creep localities and geologic exposures in November and December 1991 and January 1992. Observations below are described from northwest to southeast.

Northern segment

Main trace

South of Suisun Bay, deformation of the Waterfront Road Bridge over Pacheco Creek (Locality 10, Figure 3) is the northernmost evidence for the location of the main trace of the Concord fault noted by Sharp (1973). Sharp (1973) projected the fault to the southeast based on similar deformation of the Santa Fe Railroad Bridge (Locality 11, Figure 3) and the linear west-facing escarpment of "Tank Farm Hill".

Distress to the Waterfront Road bridge consists of an apparent clockwise rotation of the bridge section between the west abutment and westernmost pier. This apparent rotation has caused the joint in the bridge deck above the pier to open to as much as 5 cm on the south side of the bridge and to compress on the north side of the bridge, forcing joint filler to be extruded above the pavement surface.

The clockwise rotation of the bridge deck is consistent with right-lateral displacement of the west abutment relative to the westernmost pier. An alternative explanation advanced by Rogers/Pacific (1988), that dredging of the creek channel caused settlement of the bridge, seems less likely because only the eastern quarter of the bridge is over a navigable channel. Presumably, only this part of the channel would be dredged. No deformation of the bridge adjacent to the navigable channel or at any other of the seven identical piers between the navigable channel and the west abutment was observed. Poor foundation conditions at the west abutment is a possible explanation, however, if the abutment is founded on bay mud that is settling differentially or moving northward toward Suisun Bay.

Distress to the Santa Fe Railroad bridge (Locality 11, Figure 2) was also field checked. A slight right-lateral deflection in the less traveled of two rail lines exists near the west bank. There does not appear to be a related rotation of the concrete bridge deck similar to the Waterfront Road bridge.

Eastern traces

Evidence for creep on the short trace mapped by Sharp (1973) in the Avon area was field checked. At the north end of this trace is a warehouse where Sharp shows a "RL flexure in building". This is an old structure with a concrete foundation and concrete slab floor. The only distress observed was the outward bowing of the top of a retaining wall on the west wall of the building. To the south, no zone of cracks or pattern of cracks suggestive of right-lateral creep were observed in asphalt driveways or in Waterfront Road. Nearly equal right-lateral deflections of three railroad sidings south of Waterfront Road were verified (Figure

3). Other right-lateral deflections in nearby guard rails and the clockwise rotation of part of a concrete walkway were also noted on trend to the south. Although all of these features may have non-tectonic causes, the similar amounts of deflection in these features suggests fault creep.

"Small RL offset of concrete walls" were noted by Sharp at two locations to the south. The walls referred to are at about the same location as two pipeline ways, each of which consists of two parallel walls about 5 or 6 feet apart connected by a slab at the base of the walls (Locality 3, Figures 2&3). These two pipeline ways, which were constructed in the 1930's (J. Staton, Tosco Corp. p.c. 1991), cross the trace of the fault mapped by Sharp. No right-lateral deflections could be found in either, although vegetation partly hindered observations. A "Small RL offset of curb" was noted by Sharp at the south end of this trace. A curb with an apparent right-lateral offset of about 1 cm was verified at about this location, but the deflection coincides with a joint between curbs with two different types of aggregate. suggesting that this may represent the joint between curbs of different ages. No cracks were found in the adjacent street and no corresponding offset was found in the curb and low walls on the opposite side of the street.

A recent trenching study by Harding Lawson Associates (in progress) investigated this trace of the fault. HLA's trench was adjacent to the northern locality where Sharp noted offset walls (Locality 3, Figures 2 and 3). The trench exposed slightly east-dipping alluvium and paleosols to a depth of about ten feet. No indication of faulting or steeply dipping structure of any kind was observed in the trench by either G. Waterhouse of HLA or C. Wills of DMG.

The trace of the fault shown by Sims (1973) east of "Tank Farm Hill" could not be verified as geomorphic or tonal features on aerial photographs.

Another possible east trace has been mapped by Hart (unpublished aerial photo interpretation) along the east flank of "Tank Farm Hill". This trace is defined by a scarp and broad sidehill bench on the east flank of "Tank Farm Hill" and a series of related tonal lineaments. Trenches by Harding Lawson Associates (1982, AP-1542) crossed a possible northward projection of this zone. Harding Lawson reports no faults in horizontally bedded to slightly east-dipping alluvium. No trench investigations have been done in the tank farm area to the south where geomorphic indications of faulting are most convincing. A road cut near the south end of this possible fault shows disrupted bedding in older alluvium, however (Locality 12, Figure 3). This disrupted bedding and a tonal lineament in young alluvium to the south suggest late Quaternary and possibly Holocene faulting.

Fault related geomorphic or tonal features were somewhat obscured by roads, trails, and dikes in the tank farm before the 1939 aerial photographs were taken. Thus small-scale geomorphic features indicative of Holocene displacement may have been destroyed.

This possible strand of the fault was field checked for evidence of creep. Apparent right-lateral deflections of two chain-link fences and a petroleum pipeline were noted, but these features commonly have random irregularities unrelated to fault creep. Additionally, a vehicle has clearly run into one of the fences at about the location of the deflection. These deflections provide a weak suggestion of fault creep. No more conclusive evidence, such as offset curbs or roadways or left-stepping cracks was found.

Central segment

The central segment is, by far, the most well-defined segment of the Concord fault. Beginning at the segment boundary, approximately located where the fault and the Walnut Creek channel diverge, the fault is defined by a series of sharp scarps and tonal lineaments (Figure 3).

In the industrial park area north of Concord Ave. the fault is locally defined by a low southwest-facing scarp and tonal lineament (probably a groundwater barrier which is reflected in soil and vegetation contrasts). This feature is approximately parallel to, but about 200 feet east of the trace shown by Sharp. It closely corresponds to the locations of faults found in exploratory trenching (Burkland and Associates, 1973, AP-73; 1974, AP-1). Cracks in pavement and two curbs that are right-laterally offset by less than 2 cm were also observed along this part of the fault (locality 13, Figure 3). The cracks do not form a clear en echelon pattern, however, and other curbs along this trend are not deflected. It is not clear if these features are due to fault creep.

To the southeast, the fault forms a very straight scarp and tonal lineament from Concord Ave. to the east side of Keller Lake. The geomorphically defined trace closely, but not exactly, corresponds to the trace mapped by Sharp. It also closely corresponds to the locations of faults found in exploratory trenches. Evidence for creep between California Street and Keller Lake includes localities mapped by Sharp as well as several other features along the same trace. Clear expression of fault creep includes: 1) Left-stepping cracks in the parking lot north of Salvio Street (Locality 14, Figure 3), 2) a deformed building between Salvio Street and Willow Pass Road, just west of Mira Vista Terrace (Locality 15, Figure 3), 3) left-stepping cracks in Willow Pass Road and to the south in a parking lot east of Mira Vista Terrace (Locality 16, Figure 3), and 4) offset curbs and cracks in the street at Ashbury Drive (Locality 17, Figure 3).

The secondary trace of the fault mapped by Sharp (1973) and ESA (1977)(their lineament "C", Figure 2) extending northwest from the west side of Keller Lake forms a low scarp at the lake and a tonal lineament to the north. The tonal lineament may be partly artificial, however, as it follows a walkway on 1939 photos and margins of fields on 1950 photos. Other secondary faults of Sharp, apparently mapped on the basis of creep evidence, do not coincide with geomorphic or tonal features visible on aerial photos. Other secondary faults of ESA can be partly verified as tonal lineaments. Lineament "B" consists of weak tonal lineaments through a partially developed area, locally suggestive of paths or trails. Lineament "D" could not be verified. Lineament "E" consists of tonal lineaments visible on 1939 aerial photos, but not on 1950 photos. None of these tonal lineaments are associated with geomorphic features suggestive of active faulting.

Keller Lake (Locality 18, Figure 3), the most prominent neotectonic landform along the fault, has formed as a sag pond at a small right bend in the fault zone. From Keller Lake a series of tonal lineaments and scarps can be traced to the southeast. A sharp right-lateral deflection of Galindo Creek also provides clear geomorphic evidence for the location and sense of displacement of the recent trace of the Concord fault. South of Galindo Creek, a narrow zone of left-stepping en echelon cracks and right-laterally offset curbs was observed in Systron Drive beneath the elevated BART tracks (Locality 19, Figure 3). Southwest-facing scarps and tonal lineaments mark the southern end of the central segment. Deflected drainage gutters noted by Sharp were verified at two locations and observed at another locality to the south. The northern of these locations corresponds to an area of high ground water and extensively damaged pavement, suggesting that a ground-water barrier may coincide with the creeping fault (Locality 20, Figure 3). About 200 feet east of the creep localities, a southwest-facing scarp parallels the trace mapped by Sharp. This scarp is about 5 feet high and can be followed for 500 feet across a trailer park. It may represent a fault scarp that has been enhanced and moved by grading. On the adjacent trailer park to the south, Sharp noted that the scarp had been "regraded to smooth slope".

A tonal lineament, visible on 1939 USDA aerial photos, extends to the southeast along a straight projection of the central segment, about 500 feet southwest of Sharp's trace (Locality 21, Figure 3). In the field, a shallow swale approximately follows part of this tonal lineament, but no distinct geomorphic features could be found along most of it. A zone of weakly right-laterally deflected curbs and gutters parallels this lineament, but lies slightly to the west. The deflection of curbs suggest fault creep, but deflections are typically broad warps, rather than sharp deflections and no left-stepping patterns of cracks were found in adjacent asphalt paving. The groundwater anomaly noted by J.V.Lowney and Associates (1977, C-300) also suggests that a groundwater barrier, probably fault related, exists nearby. The lack of fault related features observed by J.V. Lowney and Associates in their 10-foot deep trench suggest that the fault does not exist at this location. But it is also possible that the alluvium is so young that clear fault expression has not developed.

A zone of tonal lineaments, scarps and side-hill benches diverges from the mapped trace of the Concord fault and trends southeasterly up the slope of Lime Ridge from the trailer park area (Figure 3). This zone parallels a contact (shown as depositional) between sandstone and shale of the Eocene Kreyenhagen Formation (Dibblee, 1980a). Geomorphic features in the bedrock ridge are broad and degraded, suggesting that they are not due to recent faulting. No clear evidence for creep was observed along this zone, although zones of cracks cross two roads in a trailer park. The individual cracks within these zones are parallel to the roads, similar to the most common type of non-tectonic cracks in asphalt roads, but the zones of cracks cross the roads at about a 30° angle and the cracks form a crude left-stepping pattern. Along the trend to the southeast, no cracks or offsets were observed in streets or in the Contra Costa Canal.

<u>Southern segment</u>

The southern segment of the Concord fault is roughly defined by the southwest-facing linear front of Lime Ridge. On a more detailed scale, however, few geomorphic features suggestive of recent fault movement can be observed along this segment. A discontinuous series of linear drainages, tonal lineaments, and right-laterally deflected small drainages suggest an alignment along the base of Lime Ridge (Figure 3). Some or all of these features could be related to resistant layers of bedrock or other non-tectonic causes, however. Other tonal lineaments in the alluvium of Ygnacio Valley to the west parallel the mapped trace of the fault and are probably of recent origin. They are not clearly related to faulting, although some can be observed on both 1939 and 1950 aerial photos.

The position of Pine Creek along the eastern side of Ygnacio Valley suggests that faulting closely follows the base of Lime Ridge, at least as far south as Ygnacio Valley Road. Pine Creek flows from the northwestern flank of Mt Diablo northwestward through the Ygnacio Valley. Near Ygnacio Valley Road it turns toward Lime Ridge, then it flows northwestward along the base of the ridge to the boundary between the southern and central fault segments. The stream directly along the base of the ridge, rather than near the center of the valley, suggests that part of the valley floor has been tilted downward toward Lime Ridge. Faulting along the base of Lime Ridge, roughly coincident with the channel of Pine Creek, seems the most likely explanation of this.

The right-laterally deflected drainage, just north of Ygnacio Valley Road (Locality 22, Figure 3), a questionable right-laterally deflected drainage south of the road and tonal lineaments and sidehill benches in bedrock suggest a zone of faulting. Unfortunately a small dam and stock pond have been constructed on the deflected drainage, so field checking was not possible. Roadcuts on Ygnacio Valley Road and the area to the south were field checked. Neither of these localities provided information about the existence or activity of faulting, although the road cuts show that the bedrock in this area is so extensively brecciated that it is not possible to distinguish bedding.

At the south end of the fault zone, the zone of features becomes more diffuse. Two tonal lineaments, each of which appear to coincide with small right-laterally deflected drainages (Locality 23, Figure 3), may be related to faulting or resistant bedrock.

Trenches by Engeo, (1987) and Geosoils (1986) (both AP-2074) found a zone of disrupted bedding (Engeo, trench 3) and a zone of "intensely sheared" and "highly fractured" bedrock (Geosoils, trench 2) where they crossed the tonal lineaments. Neither the geomorphic features nor the trench logs indicate Holocene faulting. Both Engeo and Geosoils trenched down the crest of a ridge, where soils are likely to be thinner and younger, rather than in the adjacent swale, where young colluvial deposits might have been found.

Tonal lineaments that are also suggestive of faulting were observed west of the fault trace mapped by Sharp (1973) in the alluvium of the Ygnacio Valley. These tonals (Figure 3) generally follow a projection of the fault from the south end of the central segment (Locality 21, Figure 3) to the North Gate Road Area (Locality 24). These tonals are generally parallel to the trend of the Concord fault but also nearly parallel to the margins of fields in 1939 and 1950 aerial photos (Locality 25, Figure 3). Some of these lineaments have been modified by agricultural activities and some may be entirely man-made.

One of these lineaments (Locality 26, Figure 3) is a straight tonal contrast between dark-toned soil on the west and lighter soil on the east. This tonal contrast crosses rows of trees in an orchard at a low angle and is visible on both 1939 and 1950 photos. The appearance of this feature suggests a groundwater barrier, probably related to active faulting.

The traces of the fault which has been located in trenches east of North Gate Road (Terrasearch, 1987, AP-2327; Engeo, 1989, AP-1840; Berlogar, 1981; Harding Lawson, 1984; Geosoils, 1986, Engeo, 1987, AP-2074) generally follows a weak tonal lineament visible on 1939 aerial photos, (Localities 7a,b and c, Figure 2) but no geomorphic evidence for active faulting was observed along this lineament.

Troughs and tonal lineaments west Sharp's trace are sharper and more prominent than those at the base of the hills. These features (Figure 3) include a sharp tonal lineament on 1973 aerial photos in an area that had been excavated for a borrow pit. This trace is just west of the fault mapped by Burkland and Associates (1973, AP-2083)(Locality 24a, Figure 3). On older aerial photos (USDA, 1939, 1950) a slight scarp and tonal lineament partly coincides with the tonal lineament in the borrow pit. The southwest facing "break-in-slope" (scarp) noted by Harding Lawson Associates (1990, AP-2373), to the northwest can be verified on 1939 and 1950 aerial photos and aligns with the tonal lineament (Locality 24b, Figure 3). In the field, this scarp is a broad, gently sloping scarp in older alluvium. The maximum slope measured was 9°. The scarp is formed in clayey silt alluvium. Soils exposed in numerous, shallow trenches excavated for the installation of drainage pipes across the scarp consisted of a thin (partially stripped?) dark brown A horizon and a red-brown (5YR3/4) B horizon with angular blocky structure and moderate clay films. This soil is similar to that described by Burkland and Associates (1973, AP-2083), Terrasearch (1987, AP-2327), and Engeo (1989, AP1840) and radiocarbon dated by Engeo. The color and development of this soil suggests that the late Pleistocene age reported by Engeo is reasonable.

To the southeast, other features follow the east side of a low bedrock ridge. Westward flowing streams cross the valley east of North Gate Road in very shallow meandering channels then are notably incised through the ridge. Streams are also right-laterally deflected as they begin their insised segments. This suggests active tectonism, with the ridge rising into the path of antecedent streams. As discussed above, trenching studies have found faults in bedrock (Engeo 1989, AP-1840), dipping soils or depositional contacts (WGC 1990, AP-2393), and faults in alluvium (Engeo, 1990, AP-2434). Together, these features suggest that a zone of faults trends about N15°W through the trenches of Engeo and just east of the trenches of WGC, perhaps obscured by North Gate Road.

SEISMICITY

Seismicity recorded between 1968 and 1991 shows a clustering of earthquakes at the northern end of the central segment and an alignment of earthquakes extending to the south (Figure 4). The alignment of earthquakes follows the surface trace of the Concord fault but diverges to the south. The clear alignment ends near the boundary of the central and southern segments. To the south, small clusters of earthquakes generally follow the southern segment. The largest instrumentally recorded earthquake in the area, a M 5.4 event in 1955, occurred near the cluster of earthquakes on the central segment (Real and others, 1978). No coseismic fault rupture was reported for this event.

To the north, the northern segment is seismically quiet and may represent a seismic gap (Oppenheimer and MacGregor-Scott, 1991). The right stepover to the Green Valley fault and the Green Valley fault itself are also seismically quiet.

To the south, the possible left step between the Concord and the Greenville faults is seismically quiet. The right step between the Concord and Calaveras faults, however, has been the site of two significant earthquake swarms. The 1970 Danville swarm (Lee and others, 1971) and the 1990 Alamo swarm (Oppenheimer p.c. 1991) occurred mainly on northeast trending alignments and probably have left-lateral focal mechanisms (Figure 4). These swarms suggest that strain is being transferred from the Calaveras to the Concord fault through a series of northeast-trending left-lateral faults.

CONCLUSIONS

The Concord fault is a N30°W-trending right-lateral fault of the San Andreas fault system. As shown on current Alquist-Priolo Special Studies Zones maps (CDMG, 1974,1977), it extends for about 18 km along the edge of Ygnacio Valley from the base of Mount Diablo to the south shore of Suisun Bay.

Northern segment

Main trace

The main trace of the Concord fault, as mapped by Sharp (1973), is generally concealed by marshes near the mouth of Pacheco Creek and the linear channel of Walnut Creek. The west-facing escarpment of "Tank Farm Hill" and smaller escarpments to the south suggest that the fault generally follows the trace mapped by Sharp. Interpretations of borings and a gravity survey by Rogers/Pacific (1988) also support this general location. Interpretation of borings logged by Caltrans (1979) and groundwater levels reported by Engeo (1977) suggest that the fault is concealed by the Walnut Creek channel beneath the Imhoff Drive and Highway 4 bridges. Right-lateral deflections of the Waterfront Road and Santa Fe Railroad bridges are consistent with fault creep, but poor foundation conditions could also be contributing the distress.

Eastern traces

The short eastern trace mapped by Sharp (1973) at Avon is defined by several right-laterally offset features that indicate fault creep. Some of the features mapped by Sharp were verified, and several other right-laterally deflected features along the same trend were noted. Although any of these features could have non-tectonic causes, their alignment and similar amounts of deflection indicate faulting. This trace also lies along an elongate hill underlain by Pliestocene alluvium which probably represents a pressure ridge. Additional subsurface data would help to confirm this fault, but the existing creep data strongly suggests active faulting.

The eastern trace of Sims and others (1973) is not defined by geomorphic features or fault creep, and has not been located in several trenching studies mostly conducted at its south end. The existence of this inferred fault strand is doubtful.

An inferred active strand of the Concord fault is defined by a long linear bench and associated broad scarp and tonal lineaments along the eastern flank of "Tank Farm Hill". This inferred fault is reasonably well defined but lacks small-scale features that would demonstrate active faulting. However, the association of these features along the margin of an elongate hill of uplifted older alluvium suggests a tectonic origin. "Tank Farm Hill" appears to be either a horst or a faulted anticline flanked by strands of the Concord fault. Thus, based on geomorphic evidence and structural relationship this strand of the fault is "sufficiently active and well-defined" for zoning.

Central segment

The central segment of the Concord fault is well-defined by geomorphic features formed in Quaternary alluvium. The strongest geomorphic evidence for active faulting includes a southwest-facing scarp, a sag pond (Keller Lake), and the right-lateral deflection of Galindo Creek. Fault creep, first noted by Sharp (1973) and monitored by Galehouse (1990), demonstrates that historic surface offset is occurring along parts of the geomorphically defined trace. Trenching studies have shown that faults in near-surface materials also coincide with the geomorphic expression. This coincidence of different types of data precisely locates the fault and demonstrates that it is active.

Geomorphic expression is less well-defined at the southern end of the central segment and evidence for creep also becomes weaker. The tonal lineament extending through localities 20 and 21 (Figure 3) suggests active faulting. The groundwater anomaly noted by J.V. Lowney and Associates (Locality 6, Figure 2) generally supports this location of the fault, but the lack of any expression of faulting identified in their trench leaves some doubt about the existence of this fault.

Short, subsidiary faults west of the main trace of the Concord fault in central Concord have been mapped based on creep by Sharp (1973) and based on interpretation of aerial photos by ESA (1977). One feature that could be interpreted as a fault was found in a trench by Zickefoose and Associates (1975, AP-456) but no other indications of faulting were found in other trenches on this trend. None of the other consultants who trenched across proposed subsidiary traces reported faults in the subsurface.

Southern segment

The surface trace of the southern segment is generally defined by the base of the southwest-facing escarpment of Lime Ridge. The linear channel of Pine Creek, along the base of the ridge, provides the strongest indication of the location of the fault. The tonal lineament at locality 26 (Figure 3) suggests a groundwater barrier related to recent faulting. Few ephemeral geomorphic features suggestive of active surface fault rupture have been identified along this segment. As shown on Figure 3, other features to the south suggestive of active faulting include tonal lineaments, deflected drainages and other features at the base of Lime Ridge, and tonal lineaments in the valley. However, the features in the bedrock of Lime Ridge lack geomorphic evidence of recent faulting and most features in the alluvium, although probably recent, are not clearly faults.

A weak tonal lineament where Terrasearch (AP 2327), Engeo (AP 1840) and Berlogar (AP 2074) have located a fault and recommended building setback zones may relate to the bedrock faults located in trenching.

Geomorphic features that are more distinct and probably represent faults at least as recent as those listed above include the scarp at Arbolado Park and extending to the northwest (Locality 24b, Figure 3), the faint tonal lineament that follows the fault located by Burkland and Associates (AP 2083)(Locality 24a, Figure 3), and the alignments of tonal lineaments, troughs and disrupted drainages near North Gate Road. The geomorphic features along North Gate Road, combined with the sharp, down-to-the-east step in bedrock between trenches by WGC (AP 2393) and Engeo (AP 1840) and the fault found in latest Quaternary alluvium by Engeo (AP 2434) suggest that there has been surface rupture on a broad zone of distributive faults in latest Pleistocene to Holocene time.

RECOMMENDATIONS

- Traces of the Concord fault highlighted in yellow on Figure 2 and Figure 3 should be zoned under the Alquist-Priolo Special Studies Zones Act as follows:

On the Port Chicago quadrangle (now called the Vine Hill quadrangle) the main trace of Sharp (1973) (Figure 2) should be shown as concealed (dotted line) except at the Waterfront Road and Santa Fe Railroad Bridges where it is inferred. The eastern trace of Sharp should remain unchanged and the inferred trace on the east side of "Tank Farm Hill" should be added. The eastern trace of Sims and others (1973) should be removed.

On the Walnut Creek quadrangle, the zoned traces of Sharp (1973) should be replaced with those based on trenching and geomorphic expression summarized in this report.

On the Clayton Quadrangle, the zoned traces of Sharp (1973) should be replaced with those based on trenching and geomorphic expression summarized in this report.

References on the Vine Hill, Walnut Creek and Clayton Quadrangles should be Sharp (1973) and this report.

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REFERENCES CITED

Advance Soil Technology, Inc., 1988, Soil investigation, Clayton Road and Sutter Street, Concord, CA: unpublished consultants report, 10 p. (AP-2238).

Bay Soils, Inc., 1979, Geologic and soils report for Higher Heights School Complex, North Gate Road, Walnut Creek, CA: unpublished consultants report, 36 p. (C-651-duplicate of AP-1840).

Bay Soils, Inc., 1980, Geologic and soils investigation, North Gate Subdivision, North Gate Road, Walnut Creek, CA: unpublished consultants report, 53 p. (AP-1840).

Berlogar, Long & Associates, 1974, Soils investigation for the El Paseo Center, Concord, CA: unpublished consultants report, (C-778).

Berlogar, Long & Associates, 1974, Engineering geologic investigation, Monument Service Center, Concord, CA: unpublished consultants report, 4 p. (AP-124).

Berlogar, Long and Associates, 1974, Engineering geologic investigation, Lehmer Oldsmobile Prop, Willow Pass Road and Concord Blvd, Concord, CA: unpublished consultants report, 5 p. (C-80).

Berlogar, Long & Associates, 1976, Engineering geologic investigation of Breiling Property, Willow Pass Road & Mira Vista Terrace, Concord, CA: unpublished consultants report, 6 p. (AP-431).

Berlogar, Long & Associates, 1978, Geotechnical investigation, Historic Ivey House relocation, Mira Vista Terrace and Concord Boulevard/Clayton Rd., Concord, CA: unpublished consultants report, 7 p. (AP-759).

Berlogar, Long & Associates, 1978, Soil investigation for proposed office building, Willow Pass Road and Mira Vista Terrace, Concord, CA: unpublished consultants report, 9 P. (AP-134).

Berlogar, Long and Associates, 1979, Geologic hazards investigation for Bayberry Convalescent Hospital, Concord, CA: unpublished consultants report, 17 p. (C-363).

Berlogar Geotechnical Consultants, 1981, Geotechnical investigation, Rancho Paraiso, Contra Costa County, CA: unpublished consultants report, 16 p. (AP-2074).

Berlogar Geotechnical Consultants, 1989, Fault investigation, Concord Automobile Sales and Service Center, Concord Avenue at Market Street, Concord, CA: unpublished consultants report, 6 p. (AP-2283).

Bryant, W.A., 1991, The Green Valley fault: Northern California Geological Society and Association of Engineering Geologists field trip guide to the geology of western Solano County, p. 1-12.

Alexander Buller Associates, Inc., 1987, Alquist-Priolo study for Concord fault A.P. No. 126-020-0750, proposed Royal Industrial Project, Commerce Avenue & Concord Avenue, Concord, CA: unpublished consultants report, 9 p. (AP-2023).

Burkland and Associates, 1973, Geologic and seismic hazard investigation, Walnut Green, Subdivision 4485 (Portion of Trefethen Property), Walnut Creek, CA: unpublished consultants report, 11 p. (AP-2083).

Burkland and Associates, 1973, Geologic and seismic hazard investigation for Buchanan Oaks Office and Industrial Park, Concord, CA: unpublished consultants report, 23 p. (C-34).

Burkland and Associates, 1973, Geologic and seismic hazard investigation, Buchanan Oaks Office and Industrial Park, Concord, CA: unpublished consultants report, 24 p. (AP-73).

Burkland and Associates, 1973, Preliminary geologic evaluation, Northwood Unit 4, Concord, CA: unpublished consultants report, 5 p. (C-527).

Burkland and Associates, 1974, Geologic and seismic hazards investigation for I. Deutscher Co. Warehouse, Concord, CA: unpublished consultants report, 10 p. (C-68).

Burkland and Associates, 1974, Geologic and seismic hazards investigation, Deutscher Co. Warehouse, Concord, CA: unpublished consultants report, 18 p. (AP-62).

Burkland and Associates, 1974, Parcels 7 through 16, Buchanan Oaks, Concord, CA: unpublished consultants report, 2 p. (AP-1).

California Department of Transportation, 1979, Project plans for construction on state highway in and near Concord from east of Route 680 to 0.3 mile east of Peralta Road: unpublished "as-built" plans (filed with AP-1712).

California Department of Water Resources, 1964, Faults and earthquake epicenters in California: California Department of Water Resources Bulletin 28. 450 p.

California Division of Mines and Geology, 1974a, Official Special Studies Zones map of the Walnut Creek Quadrangle, scale 1:24,000.

California Division of Mines and Geology, 1974b, Official Special Studies Zones map of the Clayton Quadrangle, scale 1:24,000.

California Division of Mines and Geology, 1977, Official Special Studies Zones map of the Port Chicago Quadrangle, scale 1:24,000.

Cartwright Aerial Surveys, 1973, Aerial photographs, black and white, vertical, flight CC, numbers 3526-2-245 to 2-251, 2-182 to 2-194, 3-10 to 3-16, and 3-55 to 3-62, scale approximately 1:12,000.

Colburn, I.P., 1961, The tectonic history of Mount Diablo, California: Stanford University, unpublished PhD dissertation, 276 p.

Consulting Quality Control Engineers, 1975, Soils Investigation, Lot 29 and 30, California Street, Concord, CA: unpublished consultants report, 5 p. (AP-2609).

Consulting Quality Control Engineers, 1976, Soils Investigation, Block 2, Lots 23, 24 and 25, California Street, Concord, CA: unpublished consultants report, 5 p. (AP-308).

Consulting Quality Control Engineers and Western Geological Consultants, 1977, Soil engineering and engineering geology reports for apartment complex, southeast corner Broadway & Fremont Streets, Concord, CA: unpublished consultants report, 11 p. (AP-622).

Dibblee, T.W., 1980a, Preliminary geologic map of the Walnut Creek Quadrangle, Contra Costa County, California: U.S. Geological Survey Open File Report 80-351, scale 1:24,000.

Dibblee, T.W., 1980b, Preliminary geologic map of the Clayton Quadrangle, Contra Costa County, California: U.S. Geological Survey Open File Report 80-547, scale 1:24,000.

Dibblee, T.W., 1980c, Preliminary geologic map of the Diablo Quadrangle, Alameda and Contra Costa Counties, California: U.S. Geological Survey Open File Report 80-546, scale 1:24,000.

Dibblee, T.W., 1981, Preliminary geologic map of the Port Chicago Quadrangle, Contra Costa County, California: U.S. Geological Survey Open File Report 81-108, scale 1:24,000.

Earth Sciences Associates, 1977, Seismic hazards study for Concord redevelopment areas, Concord, CA: unpublished consultants report, 19 p. (C-781).

Earth Science Associates, 1982, Seismotectonic study of Contra Loma Dam and vicinity: unpublished consultants report, 112 p.

Ellsworth, W.L., Olson, J.A., Shijo, L.N., and Marks, S.M., 1982, Seismicity and active faults in the eastern San Francisco Bay area, in Hart, E.W., Hirschfeld, S.E. and Schulz, S.S., editors, Proceedings, conference on earthquake hazards in the eastern San Francisco Bay area: California Division of Mines and Geology Special Publication 62, p. 83-92.

Engeo Inc., 1975, Addendum to geologic investigation of January 6, 1975 for Industrial Properties, south of Arnold Industrial Highway, Concord, CA: unpublished consultants report, 2 p. (AP-67).

Engeo Inc., 1975, Geologic hazard investigation, temporary office structure near Systron Drive in Concord, CA: unpublished consultants report, 5 p. (AP-129).

Engeo Inc., 1975, Geologic investigation for industrial property north of Arnold Industrial Highway, Concord, CA: unpublished consultants report, 3 p. (AP-127).

Engeo Inc., 1976, Geologic and seismic hazards investigation of Music Hall Restaurant, Concord, CA: unpublished consultants report, 12 p. (AP-682).

Engeo Inc., 1976, Geologic and seismic hazards investigation for Concord Self-Service Station, Concord, CA: unpublished consultants report, 17 p. (AP-242).

Engeo Inc., 1976, Geologic and seismic hazards investigation, The Music Hall, Concord, CA: unpublished consultants report, 12 p.

Engeo Inc., 1976, Geologic hazard study with respect to surface fault rupture for proposed King Office Building, Concord, CA: unpublished consultants report, 12 p. (AP-199).

Engeo Inc., 1976, Geologic hazard study with respect to surface fault rupture for Fidelity National Bank, Concord, CA: unpublished consultants report, 24 p. (AP-181).

Engeo Inc., 1976, Geologic hazard study with respect to surface fault rupture at proposed commercial-industrial facilities, northern ½ block bordered by Fremont, Broadway, Market, and Sutter Streets, Concord, CA: unpublished consultants report, 1 p. (AP-430).

Engeo Inc., 1976, Geologic hazard study with respect to surface fault rupture, Proposed Commercial-Industrial Facility, Concord, CA: unpublished consultants report, 14 P. (AP-180).

Engeo Inc., 1977, Geologic feasibility study, 8 lot tract on San Miguel Road, Concord, CA: unpublished consultants report, 3 p. (AP-2572).

Engeo Inc., 1977, Alquist-Priolo Investigation of Galindo Terrace, Concord, CA: unpublished consultants report, 29 p. (AP-846).

Engeo Inc., 1977, Geologic hazards investigation for the Mekatron site in Concord, CA: unpublished consultants report, 18 p. (AP-421).

Engeo Inc., 1977, Geologic hazards study for proposed Mikes Auto Body, SE corner of Sutter and Fremont, Concord, CA: unpublished consultants report, 1 p. (AP-591).

Engeo Inc., 1977, Seismic hazard investigation for auto service center, Concord, CA: unpublished consultants report, 22 p. (AP-416).

Engeo Inc., 1977, Seismic hazard study, proposed Kiewit Office Building, Concord, CA: unpublished consultants report, 28 p. (AP-1741).

Engeo Inc., 1977, Surface fault rupture investigation for proposed apartment development at 1790 Ellis Street, Concord, CA: unpublished consultants report, 12 p. (AP-578).

Engeo Inc., 1978, Alquist-Priolo seismic hazard addendum for Joe's Tune-Up Shop, Monument Blvd., Concord, CA: unpublished consultants report, 4 p. (AP-878).

Engeo Inc., 1978, Geologic feasibility for proposed suspender factory, Concord, CA: unpublished consultants report, 3 p. (AP-819).

Engeo Inc., 1978, Geologic hazard potential for Dawson-Gaffney Site south of Arnold Industrial Highway, Concord, CA: unpublished consultants report, 3 p. (AP-1508).

Engeo Inc., 1978, Geotechnical investigation of Lake Terrace II, Concord, CA: unpublished consultants report, 3 p. (AP-853).

Engeo Inc., 1978, Manufacturing and Assembly Addition, Systron-Donner Corporation, Concord, CA: unpublished consultants report, 21 p. (AP-780).

Engeo Inc., 1978, Seismic hazard investigation of office building site, Monument Boulevard and Oakmead Drive, Concord, CA: unpublished consultants report, 23 p. (AP-1699).

Engeo Inc., 1979, Alquist-Priolo investigation of proposed office building, Broadway and Fremont Streets, Concord, CA: unpublished consultants report, 20 p. (AP-917).

Engeo Inc., 1979, Geologic feasibility for building proposed for rear of 1806 Arnold Industrial Highway, Concord, CA: unpublished consultants report, 2 p. (AP-67).

Engeo Inc., 1979, Seismic hazard study of Lime Ridge property, Concord, CA: unpublished consultants report, 9 p. (AP-1108).

Engeo Inc., 1980, Alquist-Priolo exploration for northeast corner of Lowe Lane and Industrial Parkway, Concord, CA: unpublished consultants report, 16 p. (AP-1321).

Engeo Inc., 1980, Alquist-Priolo seismic hazard investigation of automotive repair shop, Fremont Street, Concord, CA: unpublished consultants report, 18 p. (AP-1350).

Engeo Inc., 1980, Geologic and seismic hazards investigation, Concord Electric, 2130 Market Street, Concord, CA: unpublished consultants report, 7 p. (AP-1380).

Engeo Inc., 1980, Seismic hazard investigation of proposed condominiums at 2141 California Street, Concord, CA: unpublished consultants report, 19 p. (AP-1390).

Engeo Inc., 1980, Seismic hazard review for proposed greenhouse on Lot 130-270-011, Concord, CA: unpublished consultants report, 2 p. (AP-1258).

Engeo Inc., 1981, Consultation on fault location for Lambert Square, Concord, CA: unpublished consultants report, 2 p. (AP-1389).

Engeo Inc., 1981, Geologic hazard study for proposed commercial and warehouse complex, Frontage Road and Highway 4, Concord, CA: unpublished consultants report, 11 p. (AP-1468).

Engeo Inc., 1981, Seismic hazard investigation of California Street Lot, Concord, CA: unpublished consultants report, 11 p. (AP-1358).

Engeo Inc., 1981, Seismic hazards investigation for Broadway and California Street lots, Concord, CA: unpublished consultants report, 11 p. (AP-1476).

Engeo Inc., 1983, Alquist-Priolo study for Concord fault, Concord Avenue and Commerce Avenue, Concord, CA: unpublished consultants report, 13 p. (AP-128).

Engeo Inc., 1984, Alquist-Priolo study, Civic Plaza development, Galindo Street and Laguna Street, Concord, CA: unpublished consultants report, 15 p. (AP-1708).

Engeo Inc., 1984, Alquist-Priolo Study for the proposed development located at 2825 Monument Boulevard in Concord, CA: unpublished consultants report, 15 p. (AP-1660).

Engeo Inc., 1985, Alquist-Priolo study for the proposed Lime Ridge Apartments, Tioga Road, Concord, CA: unpublished consultants report, 15 p. (AP-1810).

Engeo Inc., 1987, Alquist-Priolo special study, east branch of the Concord fault, 1822 Arnold Industrial Place: unpublished consultants report, 5 p. (AP-2108).

Engeo Inc., 1987, Alquist-Priolo special study report for 2689 Monument Boulevard, Concord, CA: unpublished consultants report, 2 p. (AP-2024).

Engeo Inc., 1987, Geotechnical data for EIR Geology, Seismicity, and Soils for Rancho Paraiso, Contra Costa County, CA: unpublished consultants report, 19 p. (AP-2074).

Engeo Inc., 1987, Preliminary geotechnical feasibility study, potential CCWD water reservoir sites feasibility study, Rancho Paraiso, Walnut Creek, CA: unpublished consultants report, 6 p. (AP-2074).

Engeo Inc., 1987, Seismic hazard study for Rancho Paraiso, Walnut Creek, CA: unpublished consultants report, 20 p. (AP-2074).

Engeo Inc., 1988, Seismic hazards study, Eddy House relocation, intersection of Clayton Road and Ashbury Drive, Concord, CA: unpublished consultants report, 6 p. (AP-2156).

Engeo Inc., 1989, Alquist-Priolo seismic hazards exploration, Viola Gardens, Treat Blvd. at Navarrone Way, Concord, CA: unpublished consultants report, 16 p. (AP-2311).

Engeo Inc., 1989, Seismic hazard evaluation, 1855 Willow Pass Road, Concord, CA: unpublished consultants report, 5 p. (AP-2573).

Engeo Inc., 1989, Seismic hazard study for Northgate Road, Walnut Creek, CA: unpublished consultants report, 32 p. (AP-1840).

Engeo Inc., 1989, Seismic hazard study for Parcel A, 970 San Miguel Road, Concord, CA: unpublished consultants report, 11 p. (AP-2358).

Engeo Inc., 1989, Seismic hazard study for the Concord Cinema Square project, Concord, CA: unpublished consultants report, 12 p. (AP-2364).

Engeo Inc., 1990, Seismic hazard study for Subdivision 7454, Cox Property, Contra Costa County, CA: unpublished consultants report, 10 p. (AP-2421).

Engeo Inc., 1990, Updated Alquist-Priolo report, proposed Pepperwood development, Galindo and Laguna Streets, Concord, CA: unpublished consultants report, 17 p. (AP-1708).

Engeo Inc., 1990, Seismic hazard study for the Northgate Subdivision 7506, Contra Costa County, CA: unpublished consultants report, 16 p. (AP-2434).

Figuers, S., 1991, The tectonics of western Solano County: Northern California Geological Society and Association of Engineering Geologists field trip guide to the geology of western Solano County, p. 160-171.

Galehouse, J.S., 1990, Theodolite measurements of creep rates on San Francisco Bay region faults, in Jacobsen, M.L., compiler, National earthquake hazards reduction program, summaries of annual reports volume XXXI, U.S. Geological Survey Open File Report 90-680, p. 260-268.

Geodata Inc., 1979, Fault trace investigation, proposed subdivision 5448, Concord, CA: unpublished consultants report, 11 p. (AP-1444).

GeoSoils Inc., 1986, Fault evaluation, Rancho Paraiso, Walnut Creek, CA: unpublished consultants report, 4 p. (AP-2074).

Hallenbeck-McKay & Associates, 1976, Geologic investigation for the Adler Automotive Center, Concord Avenue at California Street, Concord, CA: unpublished consultants report, 14 p. (AP-357).

L. A. Hansen Associates, 1976, Geologic hazard investigation for proposed warehouse (J. Spray Corporation) at 2710 Monument Court, Concord, CA: unpublished consultants report, 5 p. (AP-274).

L. A. Hansen Associates, 1976, Geologic hazard investigation for Hughey Duplex site, Pcl. No. 130-320-13 on San Miguel Road, Concord, CA: unpublished consultants report, 10 p. (AP-322).

L. A. Hansen Associates, 1977, Geologic hazard investigation for Lemings Sprinkler Co., Pcl. No. 129-020-014, 2760 Cloverdale Ave., Concord, CA: unpublished consultants report, 9 p. (AP-403).

Harding-Lawson Associates, 1974,1976, Geologic evaluation, active fault risk, Benicia Industrial Park, Areas 5,8, and 9, Solano County California: unpublished consultants report, (AP-31).

Harding-Lawson Associates, 1977, Geologic and soil investigation for planned warehouse and showroom building, Concord Park and Shop Center, Concord, CA: unpublished consultants report, 27 p. (AP-665).

Harding-Lawson Associates, 1977, Soil and geologic investigation of Adler Automotive Center, HLA Job No. 8173, 001.03, Concord, CA: unpublished consultants report, 9 p. (AP-357).

Harding-Lawson Associates, 1978, Soil and geologic investigation for proposed apartment building, Concord, CA: unpublished consultants report, 24 p. (AP-666).

Harding-Lawson Associates, 1978, Supplemental geologic and soil investigation for planned warehouse and showroom building, Concord Park and Shop Center, Concord, CA: unpublished consultants report, 14 p. (AP-665).

Harding-Lawson Associates, 1979, Soil engineering services, Liquid Carbonic Corporation facility, Contra Costa County, CA: unpublished consultants report, 10 p. (C-475).

Harding-Lawson Associates, 1979, Soil and geologic investigation, Dalander Office Building, Concord, CA: unpublished consultants report, 20 p. (AP-1103).

Harding-Lawson Associates, 1980, Geologic hazards investigation, planned office building, Liquid Carbonic Corporation, Avon, Contra Costa County, CA: unpublished consultants report, 10 p. (C-475).

Harding-Lawson Associates, 1981, Geologic investigation of planned addition of the Church of the Nazarene, Concord CA: unpublished consultants report, 26 p. (AP-1378).

Harding-Lawson Associates, 1981, Fault hazard evaluation for guard house, Avon Refinery, Contra Costa County: unpublished consultants report, 2 p. (AP-1418).

Harding-Lawson Associates, 1982, Geologic investigation, planned cogeneration facility, Avon Refinery, Martinez, CA: unpublished consultants report, 15 p. (AP-1542).

Harding-Lawson Associates, 1982, Soil investigation, Central Bank office complex, Stanwell Drive, Concord, CA: unpublished consultants report, 26 p. (AP-1447).

Harding-Lawson Associates, 1984, Geotechnical investigation, Rancho Paraiso, Walnut Creek, CA: unpublished consultants report, 27 p. (AP-2074).

Harding-Lawson Associates, 1989, Revised report, fault hazard evaluation, California Hill site, Concord, CA: unpublished consultants report, 11 p. (AP-2234).

Harding-Lawson Associates, 1990, Fault hazard evaluation, Arbolado Park, Walnut Creek, CA: unpublished consultants report, 22 p. (AP-2373).

Hart, E.W., 1976, Concord fault (north end): California Division of Mines and Geology Fault Evaluation Report 2, 5 p. (unpublished).

Hart, E.W., 1990, Fault Rupture Hazard Zones in California: Division of Mines and Geology Special Publication 42, 26 p.

Hill, D.P., Eaton, J.P., and Jones, L.M., 1990, Seismicity, 1980-86, in Wallace, R.E. editor The San Andreas fault system, California; U.S. Geological Survey Professional Paper 1515, p. 115-152.

Jennings, C.W., and Burnett, J.L. 1961, Geologic Map of California, San Francisco Sheet: California Division of Mines and Geology, scale 1:250,000.

Kaldveer and Associates, 1977, Geotechnical investigation of Northwood Garden Apartments, Concord, CA: unpublished consultants report, 12 p. (AP-492).

Kaldveer and Associates, 1983, Fault location study for proposed Concord North Industrial Park, Concord, CA: unpublished consultants report, 6 p. (AP-1562).

Kaldveer and Associates Inc., 1984, Feasibility foundation investigation and fault location study for seven-acre industrial park, Contra Costa County, CA: unpublished consultants report, 10 p. (AP-1712).

Kleinfelder and Associates, 1987, Preliminary special studies zone investigation, Concord Honda, 1990 Market Street, Concord, CA: unpublished consultants report, 7 p. (AP-2053).

Alan Kropp and Associates, 1983, Fault investigation, housing complex, Concord, CA: unpublished consultants report, 14 p. (AP-1545).

Alan Kropp and Associates, 1983, Fault reconnaissance, school district bus yard, Concord, CA: unpublished consultants report, 10 p. (AP-2066).

Alan Kropp and Associates, 1986, Geotechnical investigation, central facility, Mt. Diablo USD, Concord, CA: unpublished consultants report, 12 p. (AP-2066).

J.V. Lowney and Associates, 1977, Fault location study for San Miguel Hospital, Concord, CA: unpublished consultants report, 7 p. (C-300).

Burton H. Marliave, 1981, Geological reconnaissance report for Ginocio Minor Subdivision (MS 134-80), Martinez, CA. 3 p. (C-477).

Darwin Myers Associates, 1980, Geologic hazards investigation, Contra Costa County, APN #130-341-01 and 09, Cloverdale Avenue Property, Concord, CA: unpublished consultants report, 12 p. (AP-1260).

Darwin Myers Associates, 1981, Fault hazard evaluation, Contra Costa Schools Credit Union property, 2051 Harrison Street, Concord, CA: unpublished consultants report, 15 p. (AP-1412).

Darwin Myers Associates, 1982, Geologic reconnaissance, Assessor's Parcel # 105-212-021, City of Concord: unpublished consultants report, 5 p. (AP-2610).

Darwin Myers Associates, 1983, Fault hazard reconnaissance, portion of Ellis Lake Park, Concord, CA: unpublished consultants report, 14 p. (AP-1635).

Darwin Myers Associates, 1983, Fault hazard evaluation, Bonifacio Condominiums, 1965 Bonifacio Street, APN 112-191-991, Concord, CA: unpublished consultants report, 12 p. (AP-1667).

Darwin Myers Associates, 1984, Fault investigation, Concord Plaza, Building A, Concord, CA: unpublished consultants report, 18 p. (AP-1695).

Darwin Myers Associates, 1984, Geologic reconnaissance, proposed theater facility, Bisso Lane and Gasoline Alley, Concord, CA: unpublished consultants report, 13 p. (AP-1709).

Darwin Myers Associates, 1985, Fault hazard investigation, MS 54-85, APN 138-050-005, Contra Costa County, CA: unpublished consultants report, 18 p. (AP-1840).

Darwin Myers Associates, 1987, Fault hazard investigation, 1800 Concord Avenue, Concord, CA: unpublished consultants report, 12 p. (AP-2028).

Darwin Myers Associates, 1990, Fault hazard reconnaissance, Hyrail property, southeast quadrant Highway 4/ Walnut Creek Channel, Concord, CA: unpublished consultants report, 15 p. (AP-2438).

Poland, J.F., 1935, Ground-water conditions in Ygnacio Valley, California: Stanford University, unpublished M.A. thesis, 83 p.

Purcell, Rhoades & Associates, 1975, Geologic and soil investigation for a proposed 70 lot subdivision of Tract 3921, San Miguel Road, Concord, CA: unpublished consultants report, 19 p. (AP-631).

Purcell, Rhoades & Associates, 1976, Geologic investigation of Lots 24 through 29, Harrison Street, Concord, CA: unpublished consultants report, 12 p. (AP-361).

Purcell, Rhoades & Associates, 1977, Geologic investigation, Subdivision 5134, Ellis and Laguna Streets, Concord, CA: unpublished consultants report, 9 p. (AP-512).

Purcell, Rhoades & Associates, 1977, Geologic investigation, southeast corner of Ellis and Laguna Streets, Concord, CA: unpublished consultants report, 8 p. (AP-755).

Purcell, Rhoades & Associates, 1978, Geologic and seismic investigation for 29 acre parcel, San Miguel Road south of Treat Boulevard, Concord, CA: unpublished consultants report, 9 p. (AP-781).

Purcell, Rhoades & Associates, 1978, Geologic investigation for Bisso Property, located at 1581 Concord Avenue, Concord, CA: unpublished consultants report, 17 p. (AP-870).

Purcell, Rhoades & Associates, 1978, Geologic investigation for Bisso Property, located at 1581 Concord Avenue, Concord, CA: unpublished consultants report, 17 p. (AP-941).

Purcell, Rhoades & Associates, 1978, Soil & geologic investigation for proposed office building, Ashbury Dr. & Galindo St., Concord, CA: unpublished consultants report, 13 p. (AP-747).

Purcell, Rhoades & Associates, 1978, Soil & Geologic investigation for proposed office building near Clayton Rd. & Galindo St., Concord, CA: unpublished consultants report, 16 p. (AP-746).

Purcell, Rhoades & Associates, 1980, Soil and geologic study, Vista San Miguel, Concord, CA: unpublished consultants report, 15 P. (AP-1442).

Purcell, Rhoades & Associates, 1984, Soil and foundation investigation, proposed commercial building, 2630 Monument Court, Concord, CA: unpublished consultants report, 20 p. (AP-20).

Purcell, Rhoades & Associates, 1987, Soil & geologic investigation for proposed office building, Cowell Rd. & Galindo St., Concord, CA: unpublished consultants report, 16 p. (AP-717).

Real, C.R., Toppozada, T.R., and Parke, D.L., 1978, Earthquake epicenter map of California, 1900 through 1974: California Division of Mines and Geology Map Sheet 39, 1 sheet, scale 1:1,000,000.

Rogers/Pacific, 1988, Status report, fault investigation, IT Baker Site, Vine Hill Treatment Complex, Martinez area, Contra Costa County: unpublished consultants report, 55 p. (C-780).

Sims, J.D., Fox, K.F., Jr., Bartow, J.A., and Helley, E.J., 1973, Preliminary geologic map of Solano County and parts of Napa, Contra Costa, Marin, and Yolo Counties, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-484 (also Basic Data Contribution 54), scale 1:62,500.

Sharp, R.V., 1973, Map showing recent tectonic movement on the Concord fault, Contra Costa and Solano Counties, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-505, scale 1:24,000.

Abel Soares and Associates, 1975, Geologic and seismic hazards investigation for 1.8 acre parcel between Willow Pass Road and Clayton Road immediately west of Sutter Street, Concord, CA: unpublished consultants report, 7 p. (AP-2238).

Abel Soares and Associates, 1975, Geologic and seismic hazards investigation for 1960 Concord Avenue, Concord, CA: unpublished consultants report, 4 p. (AP-159).

Abel Soares and Associates, 1977, Fault hazards investigation for 938 San Miguel Road in the Concord area of Contra Costa County, Concord, CA: unpublished consultants report, 7 p. (AP-1191).

Abel Soares and Associates Inc., 1980, Geotechnical investigation for Assessor's parcel No. 135-050-131 Pazzi Road in the Walnut Creek Area of Contra Costa County: unpublished consultants report, 10 p. (AP-2307).

Abel Soares and Associates Inc., 1989, Geotechnical investigation for 1866 Clayton Road, Concord, CA: unpublished consultants report, 10 p. (AP-2365).

Abel Soares and Associates Inc., 1989, Fault hazard investigation for 1866 Clayton Road, Concord, CA: unpublished consultants report, 30 p. (AP-2365).

Terrasearch Inc., 1973, Additional geological evaluation for proposed Subdivision 4539, lands of Ginocchio, Walnut Creek, CA, 4 p. (C-25).

Terrasearch Inc., 1978, Soil and geologic investigation on Subdivision 4984, Valley Vista Road & Pazzi Road, Walnut Creek, CA: unpublished consultants report, 50 p. (AP-2082).

Terrasearch Inc., 1981, Soil and geologic investigation on proposed mini-warehouse facility, Arnold Industrial Place, Concord, CA: unpublished consultants report, 39 p. (AP-1325).

Terrasearch Inc., 1981, Geologic investigation of proposed mini-warehouse facility, Concord Avenue at Commerce Avenue, Concord, CA: unpublished consultants report, 10 p. (AP-1394).

Terrasearch Inc., 1984, Soil and geologic investigation, North Gate I development, North Gate Road, Walnut Creek, CA: unpublished consultants report, 49 p. (AP-2081).

Terrasearch Inc., 1987, Geologic/Seismic investigation on 19-acre parcel, North Gate Road, Contra Costa County, CA: unpublished consultants report, 36 p. (AP-2327).

U.S. Department of Agriculture, 1939, Aerial photographs, black and white, vertical, flight BUU, numbers 280-18 to 280-19; 280-37 to 280-47; and 280-65 to 280-72, scale approximately 1:20,000.

U.S. Department of Agriculture, 1950, Aerial photographs, black and white, vertical, flight BUU, numbers 5G-131 to 5G-162 and 7G-99 to 7G-108, scale approximately 1:20,000.

U.S. Geological Survey, 1973, Aerial photographs, color, vertical, flight SFB area 1, numbers 1-103 to 1-117, scale approximately 1:20,000.

WAC Corp., 1984, Aerial photographs, black and white, vertical, flight WAC-84C, numbers 4-189 to 4-196 and 11-196 to 11-199, scale approximately 1:24,000.

Welch, L.E., 1977, Soil Survey of Contra Costa County, California: U.S. Department of Agriculture, Soil Conservation Service, 122 p.

Western Geological Consultants, 1978, Soils and engineering geology report, San Miguel Terrace, Subdivision 5232, Concord, CA: unpublished consultants report, 12 p. (AP-757).

Western Geological Consultants, 1979, Engineering Geology Report, Subdivision 5657, San Miguel Road, Concord, CA: unpublished consultants report, 7 p. (AP-1388).

Western Geological Consultants, 1980, Fault hazard evaluation of proposed car wash, 1305 Galindo Street, Concord, CA: unpublished consultants report, 2 p. (AP-1259).

Western Geological Consultants, 1982, Ecologic hazards study, 1600 Concord Avenue, Concord, CA: unpublished consultants report, 7 p. (AP-1450).

Western Geological Consultants, 1982, Engineering geology report, proposed warehouse addition, Cloverdale Avenue, Concord, CA: unpublished consultants report, 7 p. (AP-1449).

Western Geological Consultants, 1990, Engineering geology report investigation of 8 lots, Walnut Creek, CA: unpublished consultants report, 14 p. (AP-2393).

Wire, J.C., 1975, Engineering geologic investigation, property located on Concord Avenue and Commerce Lane, Concord, California: unpublished consultants report, 4 p. (AP-128).

Woodward-Clyde Consultants, 1979, Phase II Alquist-Priolo Geologic Study, Deluxe Check Printers Building, 2550 Stanwell Drive, Concord, CA: unpublished consultants report, 18 p. (AP-1104).

Woodward-Clyde Consultants, 1980, Geologic/seismic hazards evaluation for addition to Mount Diablo Hospital, Concord, CA: unpublished consultants report, 32 p. (C-76).

Woodward-Clyde Consultants, 1985, Phase I Alquist-Priolo geologic study of proposed Magnussen Dodge dealership at the corner of Marsh Road and Solano Way, Concord, CA: unpublished consultants report, 5 p. (AP-1809).

Neil H. Zickefoose, 1974, Geologic fault study, Parcel 130-240-001, San Miguel Road, Concord, CA: unpublished consultants report, (C-779).

Neil H. Zickefoose & Associates, 1975, Geological fault study (Z75497) of two unimproved residential properties at Fremont St. near Concord Ave., Concord, CA: unpublished consultants report, 23 p. (AP-456).

TABLE 1: Site specific geological reports within the Special Studies Zone on the Concord fault, listed numerically.

AP-file#	CONSULTANT, DATE	TRENCH ?	FAULT FOUND ?	COMMENTS
1	Burkland & Associates, 1975	yes	yes	2 trenches, faults in alluvium extend to within 4' of surface, zone up to 40 feet wide. portion of area of report AP-73
62	Burkland & Associates, 1974	yes	no	Trenches 10' deep mostly in fill.
67	Engeo, 1979	yes	no	Trench 10' deep in horizontally bedded alluvium.
73	Burkland, 1974; Engeo, 1977	yes	yes	Trenches to 11' deep fault in alluvium to within 4 feet of surface, fault zone up to 40' wide. Site includes areas of reports AP-1, 1104, and 1441.
124	Berlogar-Long, 1974	yes	no	Trench up to 10' deep in alluvium and fill.
127	Engeo, 1975	yes	no	Trenches up to 8' deep, diagrammatically logged.
128	Jeremy C. Wire, 1975; Engeo, 1983	yes	no	Trenches up to 8' deep in alluvium, diagrammatically logged
129	Engeo, 1978	yes	no	Trench up to 10' deep in horizontally-bedded alluvium.
134	Berlogar-Long, 1978	yes	yes	Trenches for previous report not included with 1978 report.
159	Abel R. Soares, 1975	yes	no	
180	Engeo, 1976	yes	no	
181	Engeo, 1976	yes	no	Trenches up to 8' deep in fill and soil.
199	Engeo, 1976	yes	no	Site at edge of SSZ.
242	Engeo, 1976	yes	no	Trench 10' deep in horizontally bedded alluvium, contact dipping 40° SW near E end of trench interpreted to be stratigraphic.
274	L.A. Hansen, 1976	yes	no	Trench 8' deep in soil & alluvium.
308	Consulting Quality Control Engineers, 1976	yes	no	Diagrammatic trench log.
322	L.A. Hansen, 1976	yes	no	Trench to 11' deep in horizontally bedded alluvium.
357	Harding Lawson, 1977 Hallenbeck-McKay, 1976	yes	yes	Trenches to 10' deep. Fault zone in alluvium up to 10' wide with a 1/2" to 3/4" wide shear zone extending to within 3' of surface.
361	Purcell, Rhoades, 1976	yes	yes	Location of fault not clear on trench logs.
403	L.A. Hansen, 1977	no	no	
416	Engeo, 1977	yes	no	Trench 10' deep in alluvium.
421	Engeo, 1977	yes	no	Steeply dipping contacts in clay alluvium? - suggest recent deformation.
430	Engeo, 1976	no	no	Update of report AP-180.

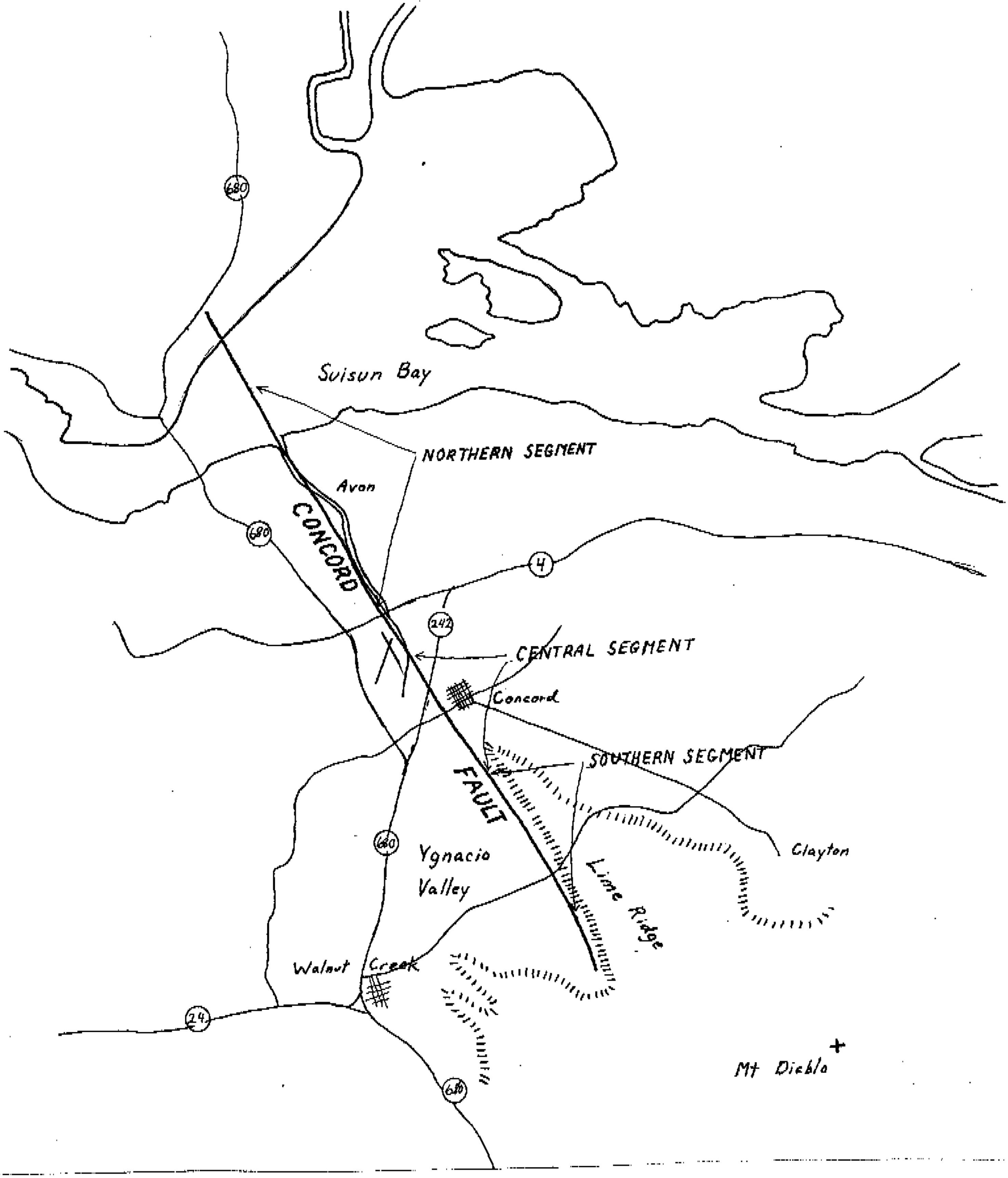
AP-file#	CONSULTANT, DATE	TRENCH ?	FAULT FOUND ?	COMMENTS
431	Berlogar, Long, 1976	yes	yes	Fault in alluvium to within 4' of surface, same location as AP-134.
456	Zickefoose, 1975	yes	yes?	"Discontinuity" in alluvial unit at end of trench interpreted to be fault.
492	Kaldveer, 1977	yes	no	Property at end of zone on east trace.
512	Purcell Rhoades, 1977	yes	no	Site at edge of SSZ.
578	Engeo, 1977	yes	no	Trench 10' deep in horizontally bedded alluvium.
591	Engeo, 1977	no	no	Site "shadowed" by adjacent reports AP-180 & AP-430.
622	Consulting Quality Control Eng, 1977 & Western Geologic Consultants, 1977	yes	no	Trenches 7' deep in soil and alluvium.
631	Purcell, Rhoades, 1975, 1976,1977, (1978 addendum)	yes	no	Trenches 5-10' deep in horizontally bedded alluvium, fault interpreted to be along E edge of property obscured by creek.
665	Harding Lawson, 1977, 1978	yes	no	Trenches 10' deep in horizontally bedded alluvium, site at edge of SSZ.
666	Harding Lawson, 1978 Engeo, 1991	yes	no	Trenches 8' deep in soil and alluvium.
682	Engeo, 1976, 1977, 1978	yes	no	Trenches 10' deep in horizontally bedded alluvium.
717	Purcell, Rhoades, 1978	yes	no	Trenches up to 10' deep in soil & alluvium.
746	Purcell, Rhoades, 1978	yes	no	Trench up to 13' deep in soil & alluvium.
747	Purcell, Rhoades, 1978	yes	no	Trench up to 10' deep in soil & alluvium.
755	Purcell, Rhoades, 1977, 1978	yes	no	Trench up to 8' deep in soil and alluvium.
757	Western Geological Consultants, 1978	yes	no	Trench up to 10' deep in soil and alluvium.
759	Berlogar, Long, 1978	yes	no	Trench to 9' deep in soil and alluvium.
780	Engeo, 1978	yes	no	
781	Purcell, Rhoades, 1978, 1988	yes	no	Trenches up to 13' deep in alluvium.
819	Engeo, 1977, 1978	no	no	Reconnaissance and literature review site on edge of SSZ.
846	Engeo, 1978	yes	no	Trench 10' deep in soil and alluvium.
853	Engeo, 1978	yes	no	Trench 10' deep in soil and alluvium.
870	Purcell, Rhoades, 1978	yes	yes	Faults in horizontally bedded alluvium extend to within 2' of ground surface. Zone up to 70' wide.
878	Engeo, 1978	no	no	Site shadowed by adjacent trenching.
917	Engeo, 1979	yes	no	Trench 10' deep in soil and alluvium.

AP-file#	CONSULTANT, DATE	TRENCH ?	FAULT FOUND ?	COMMENTS
941	Purcell, Rhoades, 1978, 1979	yes	yes	Same report as AP-870 with 1979 update.
1103	Harding Lawson, 1979	yes	no	Trench 10' deep in soil and alluvium.
1104	Woodward-Clyde, 1979	yes	no	Trenches up to 16' deep in horizontally bedded alluvium, portion of area covered by AP-73.
1108	Engeo, 1979	yes	no	Large site in hills east of mapped fault. Trenched across prominent lineament which is thought to be due to differential weathering of bedrock.
1191	Abel R. Soares, 1977, 1978	yes	no	Trench up to 9' deep in horizontally bedded alluvium.
1258	Engeo, 1980	no	no	Site shadowed by adjacent investigations.
1259	Western Geological Consultants, 1980	no	no	Reconnaissance and review of previous work only.
1260	D. Myers, 1980	yes	no	Trenches up to 12' deep in horizontally bedded alluvium.
1321	Engeo, 1980, 1981, 1984	yes	no	Trenches up to 10' deep in horizontally bedded alluvium, site near east trace.
1325	Terrasearch, 1981	yes	no	Trench 8' deep in horizontally bedded alluvium.
1350	Engeo, 1980	yes	no	Trenches up to 10' deep in horizontally bedded alluvium.
1358	Engeo, 1981	yes	no	Trenches up to 10' deep in horizontally bedded alluvium.
1378	Harding Lawson, 1981	yes	no	Trench for building on E side of property, fault on W side of property not trenched.
1380	Engeo, 1980	no	no	Site shadowed by adjacent properties.
1388	Western Geological Consultants, 1979, 1980	yes	no	Trench 8' deep in alluvium. Site on Sharp's trace.
1389	Engeo, 1981	no	no	Site shadowed by nearby trenches.
1390	Engeo, 1980	yes	no	Trench 9' deep in soil and alluvium.
1394	Terrasearch, 1981	yes	no	Trench 9' deep in horizontally bedded alluvium.
1418	Harding Lawson, 1981	no	no	Letter summary of previous work, not compete report.
1412	D. Myers, 1981	no	no	Site shadowed by adjacent work.
1442	Purcell, Rhoades, 1980	no	no	4 Borings only.
1444	Geodata, 1979	no	no	Site shadowed by adjacent trenching.
1447	Harding Lawson, 1982	yes	yes	3 Trenches observed fault location surveyed, trenches not logged, portion of area of AP-73.
1449	Western Geological Consultants, 1982	yes	no	Trench 8' deep in horizontally bedded alluvium.
1450	Western Geological Consultants, 1982	yes	no	Trenches 9' deep in horizontally bedded alluvium. Setback recommended based on review of reports for adjacent properties.

AP-file#	CONSULTANT, DATE	TRENCH ?	FAULT FOUND ?	COMMENTS
1468	Engeo, 1981	no	no	Site at edge of SSZ on east trace, no geophysical of groundwater anomalies found.
1476	Engeo, 1981	yes	no	Trenches 9' deep in horizontally bedded alluvium.
1508	Engeo, 1978	yes	no	Trench 8' deep in alluvium.
1542	Harding Lawson, 1982	yes	no	Trench up to 11' deep in horizontally bedded alluvium, site is not on mapped fault trace.
1545	A. Kropp, 1983	yes	no	Trench 10' deep in horizontally bedded alluvium.
1562	Kaldveer, 1983	yes	no	Trench #6' deep in horizontally bedded alluvium, site crosses "East trace" of fault.
1635	D. Myers, 1983	no	no	Site shadowed by trench on adjacent site.
1660	Engeo, 1984	no	no	Log of fault in Galindo Creek channel excavation included to show fault is E of site.
1666	Engeo, 1983	no	no	Same site as AP-67.
1667	D. Myers, 1983	no	no	Site at edge of SSZ.
1695	D. Myers, 1984	yes	no	Trenches 11'deep in horizontally bedded alluvium, subsidiary trace of Sharp (1993) to west questioned.
1699	Engeo, 1978, 1984	yes	no	Trenches 9' deep in fill and alluvium, fault 10' west of site based on geomorphic features.
1708	Engeo, 1984 w/1990 update	yes	no	Trench 8' deep in fill and horizontally bedded alluvium.
1709	D. Myers, 1980	no	no	Review of previous work and photo interpretation.
1712	Kaldveer, 1984 Caltrans, 1979	no	no	Geophysical profiles and groundwater data by Kaldveer suggest fault is under Walnut Creek channel west of site. Boring data by Caltrans documents discontinuities in bedding beneath Walnut Creek channel.
1741	Engeo, 1977	no	no	Fault in Walnut Creek channel to E.
1748	Purcell, Rhoades, 1984	no	no	Borings only, site at edge of AP zone.
1809	Woodward-Clyde, 1985	no	no	Review of reports on surrounding sites.
1810	Engeo, 1985	yes	no	Site at end of Lime Ridge E of mapped fault.
1840	Engeo, 1989 Bay Soils, 1980 D. Myers, 1985	yes	yes	Faults in bedrock and steps in alluvium-bedrock contact, no conclusive evidence for active faulting found.
2023	Buller Assoc. 1987	no	no	Site at edge of SSZ.
2024	Engeo, 1987	no	no	Site shadowed by adjacent studies.
2028	D. Myers, 1987	yes	no	Trench 10' deep in horizontally bedded alluvium.
2066	D. Myers, 1986	yes	yes	2' wide main trace cuts horizontally bedded alluvium. No subsidiary traces.
2074	Engeo, 1987; Harding Lawson, 1984 Berlogar, 1981	yes	yes	Faults in bedrock mapped by all consultants. Main trace of fault mapped across sw corner of site cuts bedrock but apparently not overlying soil.

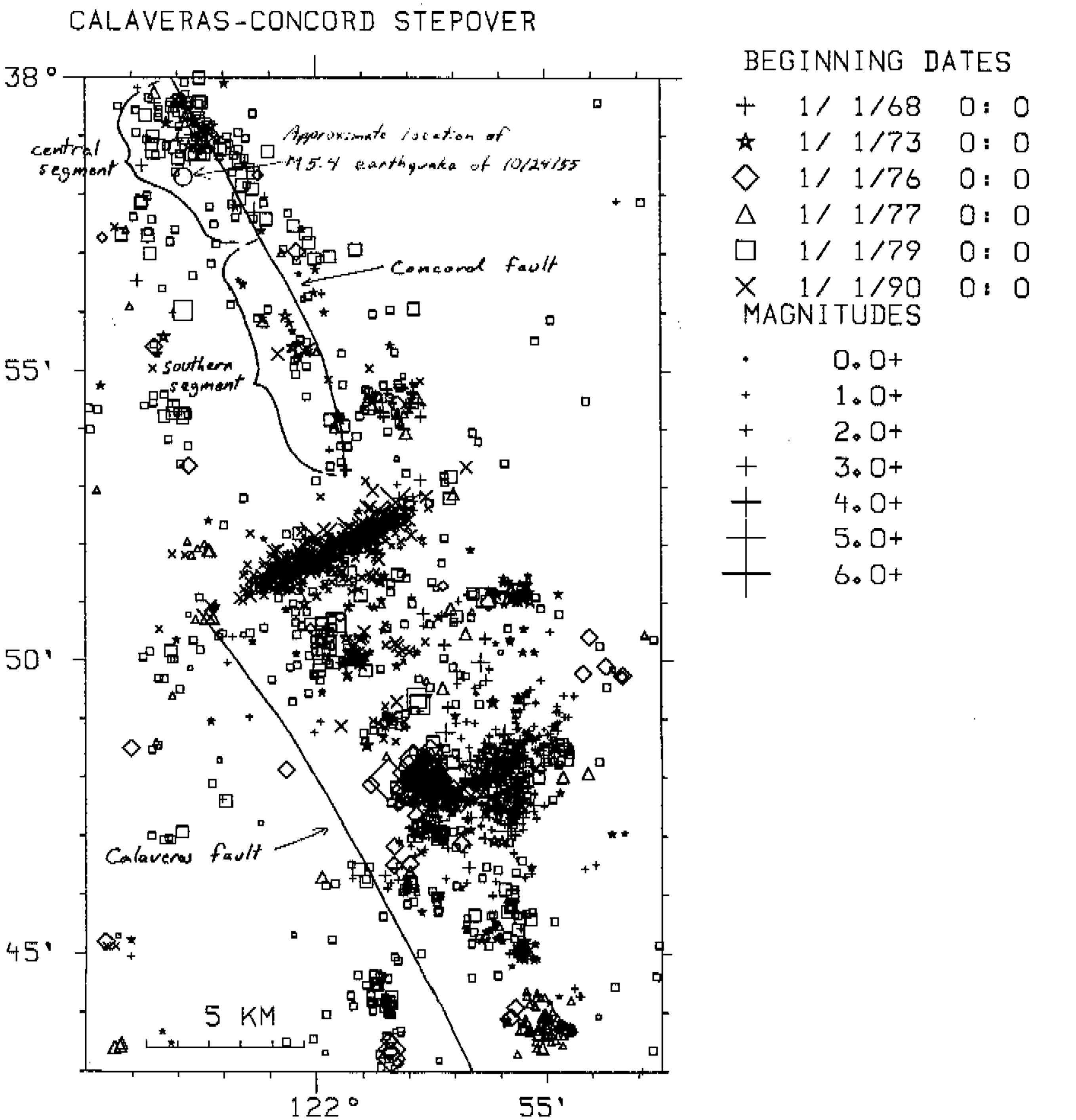
AP-file#	CONSULTANT, DATE	TRENCH ?	FAULT FOUND ?	COMMENTS
2081	Terrasearch, 1984	yes	no	Trench 8'-10' deep in horizontally bedded alluvium.
2082	Terrasearch, 1978	yes	no	Trench 7'-10' deep in soil and alluvium.
2083	Burkland, 1973	yes	yes	Fault between bedrock and alluvium exposed in 3 trenches and cut slope.
2083	Kleinfelder, 1987	no	no	Site shadowed by adjacent studies.
2108	Engeo, 1987	no	no	Site "shadowed" by adjacent report #AP-1508.
2156	Engeo, 1988	no	no	Site shadowed by adjacent studies.
2234	Harding Lawson, 1988	yes	no	Trenches 10' deep in horizontally bedded alluvium.
2238	Abel R. Soares, 1975	yes	no	Trench up to 10 deep in horizontally bedded alluvium.
2284	Berlogar, 1989	yes	no	Trenches 10' deep in horizontally bedded alluvium.
2307	Abel R. Soares, 1980	yes	no	Trench up to 10' deep, schematically logged
2311	Engeo, 1989	yes	no	Some shears in steeply dipping bedrock.
2327	Terrasearch, 1987	yes	yes	faults in bedrock in zone 35' wide, no faults in soil horizons.
2358	Engeo, 1989	yes	no	Trench 10' deep in horizontally bedded alluvium.
2364	Engeo, 1989	yes	no	Trench 8' deep in fill and alluvium.
2365	Abel R. Soares, 1989	yes	no	Trench 10' deep in horizontally bedded alluvium.
2373	Harding Lawson, 1990	yes	no	Trench 10' deep in horizontally bedded alluvium, one trench excavated on extension of fault trace by Burkland (1973, AP-2093) main trace not investigated.
2393	Western Geological Consultants, 1990	no	no	Trenches up to 8' deep in alluvium and bedrock.
2421	Engeo, 1990	no	no	Site shadowed by surrounding investigations.
2434	Engeo, 1990	yes	yes	Faults in bedrock older (?) alluvium, overlain by alluvium of Holocene age (C14 dated).
2438	D. Myers, 1990	no	no	Review of literature, aerial photo interpretation and analysis of evidence for creep.
2572	Engeo,1977	yes	no	Trench up to 9' deep in horizontally bedded alluvium.
2573	Engeo, 1989	no	no	Investigation of existing building astride creeping trace of fault.
2609	Consulting Quality Control Engineers, 1975	yes	no	Trench 6 to 7 feet deep in soils and alluvium, schematically logged.
2610	D. Meyers, 1982	no	no	Fault located west of site based on geomorphic expression and creep.
2622	Kleinfelder, 1985	yes	yes	incomplete report, trench logs missing.

AP-file#	CONSULTANT, DATE	TRENCH ?	FAULT FOUND ?	COMMENTS
C-25	Terrasearch, 1973	no	no	Fault NE of site based on geomorphology and magnetometer traverse.
C-76	Woodward-Clyde, 1980	no	no	site east of AP zone.
C-80	Berlogar, 1974	yes	yes	Fault to within 2' of surface in alluvium and soil.
C-300	J.V.Lowney,1977	yes	no	Trenches up to 10' deep in horizontally bedded alluvium.
C-363	Berlogar,1979	yes	yes	Faults to within 2' of surface in alluvium and soil. Zone 15 to 20' wide.
C-475	Harding-Lawson, 1978,1979,1980	yes	no	Trenches ≈10' deep in horizontally bedded alluvium.
C-477	Burton H.Marliave, 1981	no	no	reconnaissance of site south of AP zone
C-527	Burkland,1973	no	no	Site is east of AP zone.
C-651	Bay Soils,1979	yes	yes	Fault along bedrock-alluvium contact. See AP-1840.
C-778	Berlogar, 1974	yes	no	Trench about 5' deep in soil and alluvium.
C-779	Zickefoose,1974	yes	no	Trenches ≈7' deep in soil and alluvium??
C-780	Rogers/Pacific, 1988	no	yes	Fault defined by gravity anomaly and sheared bedrock found in borings.
C-781	ESA, 1977	no	no	Review of previous work for planning of redevelopment.
	Engeo, 1976	yes	no	Trench in soil and alluvium, log missing copy of report reviewed.



FER-231, Figure 1

Index map of the Concord fault and surrounding area showing the most prominent geographic features and fault segments discussed in the text.



FER-231, Figure 4

Seismicity of the Calaveras-Concord fault stepover zone provided by D. Oppenheimer (p.c. 1991). Northern segment of the Concord fault (not shown) is seismically "quiet" and may represent a seismic gap (Oppenheimer and MacGregor-Scott, 1991). Location of 1955 Concord earthquake from Real and others (1978).